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Future Forecasts of Industrial Solid Waste Generation: Perspectives from Consumption Pattern and Industrial Structure

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1. Introduction

The Chinese city of Shanghai has been facing an increasingly serious problem of industrial solid wastes (ISW) due to the rapid economic growth and industrialization. Further, accurate forecasting of the volumes of ISW produced is the basis of constituting environmental protection plans and the successful designing of solid waste management systems. However, the current attempts are not enough. The previous records are patently over-simplistic, or have either failed to consider industrial restructuring caused by economic growth^{1,2,3}.

This paper, attempts the construction of a systematic approach as to solve the following issues: (1) to effectively evaluate the present and future industrial structures; (2) to analyse their contributions to ISW generation; and (3) to investigate the distribution of ISW generation among industries. Research has investigated that structural changes in input coefficient are ambiguous in the short- and medium-run predictions⁴. Therefore, as a first step, our study examines the influence of industrial restructuring on economic growth, including consumption pattern and export composition, not involving the technical change. Shanghai is selected as case study with the projection horizon being 2005—2020.

2. Methodological approach

The entire systematic framework is illustrated as Fig. 1, linking three principal models—the macro-economic model, the regional input output (IO) analysis and the waste generation model. The shaded area denotes the aspects of industrial restructuring that are in accordance with the updated IO tables, introduced in section 3.

2. 1 Regional macro-economic model

The main function of the regional macro-economic model is to provide a means for economic structural analysis and economic forecasting in Shanghai. The target variables are the GDP and its composition, as private consumption (PC), government consumption (GC), fixed capital formation (I), and export (EXC). It is divided into the following five blocks: real/nominal expenditure, deflator, price, wage and labour. The influence of the national economy on Shanghai may be gauged by the relevance of the national GDP and GC in the individual equations. Further, influence of world trade is introduced as exogenous variables in the model. Moreover, conventional statistics and interpolations test validate the specification of each behavioural equation.

The predictions of Chinese GDP figures refer to the results estimated by the Chinese Academy for Environmental Planning under conditions of low-speed economic development⁵. The average economic growth rate is put at 7.3% during 2006—2010, 6.8% during 2011—2015 and 6.4% during 2016—2020. To calibrate the model, available economic indicators, are obtained from the Shanghai Bureau of Statistics and the international database (International Financial Statistics). Further, the variables denoting world trade refer to the same data as Kabeyama⁶.

2. 2 Regional input-output analysis (IO)

A transformation from the standard IO analysis based on demand-driven system is written as the following Eq. (1)

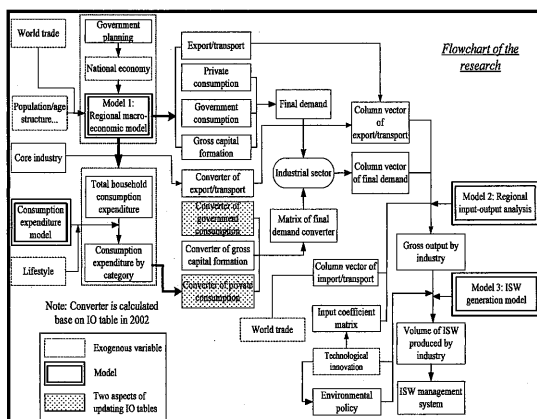


Fig. 1 The entire framework of research

$$X_{pds} = [(I - (I - \hat{M})A)^{-1} \times [(I - \hat{M})FD_{pds} + E_{pds}]] \quad (1)$$

where X_{pds} : column vector of gross output with subscript pds denoting the industrial sector; A : matrix of input coefficient; FD_{pds} : column vector of final demands; E_{pds} : column vector of export and transport to other Chinese regions from Shanghai; \hat{M} : a matrix of import coefficient with diagonal element defined as $m_i = M_i / (\sum_j x_{ij} + FD_i)$ (the subscript $i, j \in$ dimension of pds); M_{pds} : column vector of import and transport into Shanghai from other Chinese regions.

Further, in the process of calculation of the vector of FD_{pds} , the concept of the converter (CV) is introduced, as shown in Fig. 1. CV is defined as the output share of each industrial sector in the total output in the respective final demand item ($\sum CV_{pds, fds} = 1$). The subscript fds represents each individual item. In an open economy, changes in FD_{pds} usually reflect changes in consumption patterns and the composition of trade. By expressing FD_{pds} using the converter, it provides economists with the opportunity to analyze quantitatively the effects of various industrial restructuring maneuvers on each item by adjusting the converter; the converter also assists in the assessment of the impact of these changes on sectoral output.

2. 3 Waste generation model

The volume of the overall ISW produced by sector (Y_{pds}) is estimated through the following equation:

$$Y_{pds} = \hat{D}_{pds} \times X_{pds} = \hat{D}_{pds} \times \{[I - (I - \hat{M})A]^{-1} \times [(I - \hat{M})FD_{pds} + E_{pds}]\}, \quad (2)$$

where diagonal element D_i of diagonal matrix \hat{D}_{pds} is defined as the total waste generation coefficient of each sector per unit gross output, measured in tons (10 000 RMB)⁻¹. Because Shanghai has no detailed waste statistics by industry, the coefficient on the national level in 2002 is used in place. Prior to the analysis, the existing IO tables of Shanghai in the years 1987, 1992, 1997 and 2002, were aggregated into the same dimensions, comprising 24 industrial sectors. The tertiary sectors were united as pds_{24} , and all mining sectors aggregated as pds_2 , based on the *national economic industry classification* (GB/T4754-2002). Further, the dimensions of the waste table are adjusted to the same size as that of the IO table. The principal categories of ISW in Shanghai are hazardous wastes (HW), smelting residue (SR), coal-burning powder (CB), slag (SL), coal stone (CS), gangue (GA), radioactive wastes (RA) and others (OT).

3. Updating the IO table

3.1 Private consumption

PC is one of the most important factors contributing to the total GDP, and accounted for 36.55% in 2007. As mentioned above, changes in consumption patterns are analyzed in terms of adjustments to the converter, illustrated in Fig. 2. Firstly, PTCON is predicted using regression analysis, as Fig. 3 (1). Further, previous research has applied a consumption expenditure model onto the urban areas of Shanghai in order to analyze the changes in consumption patterns⁷⁾. In the consumption model, it is believed that

'saving deposits' (SAV) and the 'household size' (ANPP) are two prominent explanatory variables that affect consumer

behaviour greatly. The assumption of explanatory variables in a future year is summarized in Fig. 3 (2) and Fig. 3 (3). The prediction of SAV is obtained by an autoregressive integrated moving-average model (ARIMA). On the other hand, the value of ANPP is assumed to be decreasing gradually as 3.00 until 2010, and 2.90 until 2020. Finally, in a future year, with the predicted PTCON and the given exogenous variables, the percentage share of consumption expenditure by

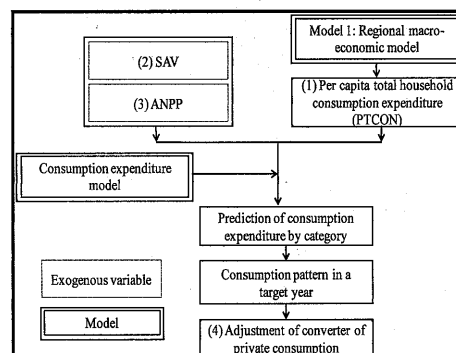


Fig. 2 Flow chart of adjustment of converter of PC

consumption category can be subsequently derived. Then, integrating with GB/T4754-2002, the converter vector of PC in a prediction year across all the industries is recalculated, as demonstrated Fig. 2 (4).

3.2 Export and transport to other Chinese regions

During the past two decades, there have been considerable changes in the export shares of each industry; these have been calculated using existing IO tables. Based on the trend of such changes, the four top sectors with relatively high shares that changed the most were as pds4, pds7, pds16, pds17. Therefore, in order to forecast export share in future years, we first set an assumption for these four sectors and readjust the share of the others. In the current paper, the forecasting methods of arriving at the export shares of the four sectors are different in each case. For each prediction year, the overall share of the other sectors is readjusted in a fixed and mutual proportion within the total share, which is maintained as '1'. In addition to the export structure, significant change also occurs in the structure change in transport to other regions within China: the two sectors, pds9 and pds24, are considered to have undergone the most change in this regard. The predictions with respect to transport structures for pds9 and pds24 are predicted by the method of regression analysis.

4. Results and discussion

4.1 Estimation of the volume of ISW produced

Compiling the fixed waste generation coefficient of each sector on a national level for the year 2002, and the existing gross output by industry in the existing IO tables for Shanghai, the estimated volume of ISW produced can be calculated for comparison with the waste statistics. The estimated volume is about 1.5 times that published in the yearbooks in 1997 and 2002, respectively. One of the reasons for the error is that the average level of technology on a national level is lower than that for a developed city such as Shanghai: this leads to a higher waste generation coefficient.

4.2 Prediction of volume of ISW produced

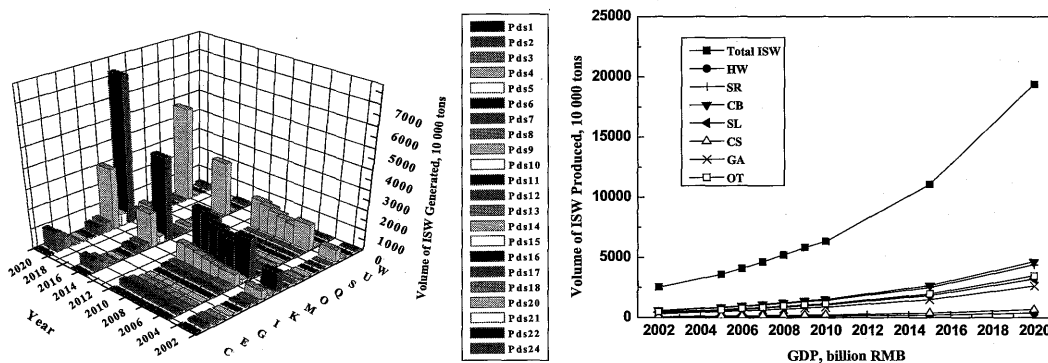


Fig. 3 Volume of ISW generation, 2002-2020 (b) Relationship between ISW generation and GDP

Fig. 3 plots the a) predicted volumes of ISW produced in each industry by waste category until the year 2020 and b) the relationship between ISW generation and GDP. Economic growth based on the development of industry will result in progressively greater volumes of ISW as we move from 2002 towards 2020. For a), four aspects are addressed. Firstly, under the assumption of unchanged technology, the volume of each type of waste will increase over the next two decades. Among the waste categories, CS has the greatest increase ratio—7.19 times by 2020—as a result of the development of the mining industry, followed by SR, which will increase 6.83 times. Furthermore, the total waste generation in 2010, 2015 and 2020 will be 2.50, 4.38 and 7.67 times, respectively, that of the 2002 levels. Secondly, it is relatively simple to identify the industrial sector that generates the largest contributions to each type of ISW. For example, in 2020, the largest component of SR was generated by pds11, at about 90% of total volumes. Therefore, for preventing and reducing the generation of SR, it will be necessary to bring about technological innovations in pds11 with immediate effect. Thirdly,

the adjustment of consumption pattern and export composition will not lead to significant change in the respective shares of each waste category to total ISW, with the currently steady rate of technological development. The different shift of alternative technologies among input structure and/or technological innovation may be more important to affect the mutual proportion. Finally, although no big changes will come into effect in the relative share between the sectors, the contributions of pds16 and pds24 will increase by 118% and 28.72%, respectively, from 2002 to 2020. The government should pay more attention to such sectors while planning its waste prevention policy.

In addition, for b), the relationship between GDP and ISW generation is not purely linear. It emerges that ISW generation is caused by economic growth that is partly engineered by industrial restructuring. As a result of the increased learning of consumer propensities towards transportation and changes in export composition, in 2020, the gross outputs of pds16 and pds17 will be up to 16.74 and 14.79 times, respectively, of the 2002 levels. Meanwhile, the indices related to the power of dispersion of these sectors are both higher than 1 (1.230 and 1.156), denoting a big influence on the production of other sectors. On the other hand, although the contribution of pds24 to the total ISW generation is small (1.20% in 2020), the sector sees a significant increase in its share of the gross output. Thus, it may be said that economic growth is no longer the sole factor affecting ISW generation; the influence of industrial restructuring is becoming progressively more important.

5 Conclusions

Predicting ISW generation is difficult for researches because of complex production processes, which in turn are affected by many factors. This paper delves deep in order to investigate the influence of industrial restructuring on ISW generation, based on the study of consumption patterns and export composition figures, and launches a reasonable attempt at projecting ISW generation of each waste category by industry on a regional level. We regard the present work as a pilot model, compiled with the current technology, which needs further improvement considering technological innovation. It can be expected that the model application will improve when local generation coefficients are supported or further research on approaching the real values is carried out. Fortunately, this growing concern is now being address.

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